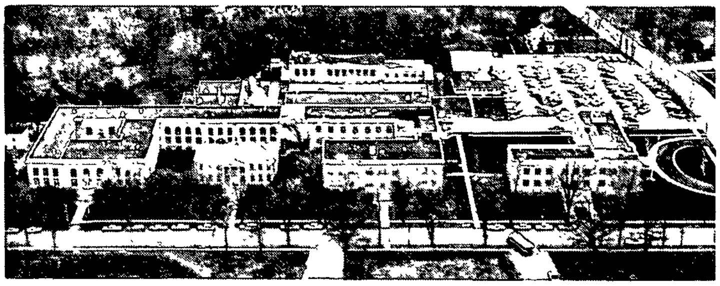

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BIOMASS AND NUTRIENT STATUS OF YOUNG QUAKING ASPEN STANDS

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INTRODUCTION

Appropriate regression equations were developed that allowed the determination of fiber and total biomass production of young quaking aspen sucker stands in the Lake States Region. Information was also obtained on the nutrient drain that resulted from various, alternative, short-rotation harvesting systems.

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BIOMASS AND NUTRIENT STATUS OF YOUNG QUAKING ASPEN STANDS

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ABSTRACT

Regression equations of the form $Ln\hat{\underline{Y}} = \underline{b}_0 + \underline{b}_1 Ln\underline{X}_1$ were established that allow the prediction of the dry weight of leaves, bolewood, bole bark, branches, total wood, total bark and total aerial biomass for individual trees.

Estimates were obtained of biomass production by young quaking aspen stands growing on upland sandy soils (site index, base age 30, 48-52) in northern Wisconsin. Regression equations were calculated that established relationships between stand age and the production of leaves, wood, bark and branches. Levels of N, P, K, Ca and Mg in leaves, bark, wood and branches were determined, thus enabling biomass data to be used to predict nutrient drain for several alternative harvesting procedures and rotation ages.

Soil nutrient levels, when compared with estimated nutrient drain due to short-rotation, whole-tree harvesting, demonstrated that the sites in question would not be seriously injured by short-rotation, whole-tree harvesting when rotations were maintained at 10-20 years and the leaves were not removed from the site.

INTRODUCTION

The aspen-birch type occupies a total area of approximately 14.9 million acres (6.0 million ha) of the total 51.5 million acres (20.8 million ha) in commercial forest lands in the Lake States Region. There are approximately 6 million acres (2.4 million ha) in Minnesota (1970) and the remaining area is divided about equally between Michigan (1958) and Wisconsin (1972). Greatly increased interest in harvesting aspen on short rotations (10-20 years) and using whole-tree harvesting methods[1] has emphasized the need for having appropriate information on total biomass, nutrient accumulation and the nutrient drain that will result when young aspen stands are harvested using varying intensities of utilization.

Biomass production from young aspen stands has been reported by Person et al. (1971), Pollard (1971, 1972), Perala (1973), and Ek and Brodie (1975). James and Smith (1977) reported on the short-term effects of surface fire on the biomass and nutrients of a 30-year-old quaking aspen stand in southern Ontario. Studies by Bella (1968), working with Canadian aspens; Zavitkovski (1971), working with aspen in Wisconsin; and Schlaegel (1975), investigating aspen stands in Minnesota, provide the type of biomass information required to estimate the nutrient drain that would result from harvesting young aspen stands. None of

[1]Harvesting the entire aerial portion of the tree.

these studies, however, considered the nutrient levels in the several components that make up the total biomass, or provide information on stand changes with age that make it possible to evaluate this aspect of short-rotation forestry.

The objectives of this study were to: (1) obtain data on the weight of bark, wood, branches and leaves for individual trees, (2) determine biomass/stand age relationships for young aspen stands, (3) obtain estimates of N, P, K, Ca, and Mg levels in the wood, bark, branches and leaves, and (4) obtain nutrient drain data associated with harvesting stands on short rotations and varying intensities of utilization.

METHODS AND MATERIALS

The overall approach used was to cut, measure and weigh trees of different sizes growing in closed stands and use this information to develop regression equations for predicting the weight of individual tree biomass components (bolewood, bole bark, branches, leaves, etc.). Height, diameter and number of stems per acre were also determined for nine aspen stands varying in age from 5 to 22 years and this information was used to examine biomass/stand age relationships. In addition, levels of N, P, K, Ca, and Mg were measured for the several biomass components and this allowed converting biomass weight into nutrient accumulation and/or drain information.

Standard field sampling techniques were employed in determining the green and dry weight of individual trees. For trees less than 2 inches in diameter, the entire tree was returned to the laboratory for separation into the biomass components of interest. Trees greater than two inches in diameter were weighed in the field and then disk samples taken every six feet up the stem and used to estimate the dry weight of bark and wood. For the larger trees, the branches were separated into three size categories, the fresh weight of each category determined and representative branch samples used to convert field wet weights into the dry weight of branch bark and branchwood for the entire tree. These same representative samples were used as a source of material for nutrient analyses. Leaf weights were obtained by stripping all the leaves from the trees, including the petioles, placing the leaves in sample bags and drying and weighing them in the laboratory.

Standard linear and curvilinear regression procedures were used to develop regression equations for predicting the weight of wood, bark, and the other biomass components of interest and to develop biomass/age relationships. Correlation coefficients ($\underline{r}^2$), plots of predicted ($\hat{\underline{Y}}$) and observed values ($\underline{Y}_i$) over tree size (D^2H) and plots of residuals ($\underline{Y}_i$ - $\hat{\underline{Y}}$) over tree age were used to judge the type of equations that gave the most useful predictions.

The total biomass for the stands of varying ages was determined by measuring sample plots that varied in size from 1/100 to 1/10 acres (4/1000 to 4/100 ha) and tallying the individual trees on each plot by height and diameter. Sample plot data were converted to dry weight/acre of wood, bark, branches and leaves. Then, by combining the per acre biomass data with the nutrient level information, it was possible to estimate the accumulated levels of nitrogen, phosphorus, potassium, calcium, and magnesium.

Nutrient levels in the leaves, bark, wood and branches were determined by using representative samples from a limited number of trees that were cut and weighed as part of the individual tree biomass sampling procedure. Nutrient levels in the leaves were based upon samples from 34 trees and the information on the nutrient levels in the bark, wood and branches were based on samples taken from 14 trees. All samples were dried at 105°C until thoroughly dry, ground in a micro-Wiley mill to pass a 40-mesh screen, and then stored in glass jars until analyzed. Moisture content was determined prior to analysis and the results corrected for moisture content. Standard emission spectrographic techniques were used to determine P, K, Ca, and Mg. Nitrogen was determined by the standard Kjeldahl procedures. Fully mature leaves were collected in late August from exposed branches in the upper and middle part of the crown. The petioles were left on the leaves and included in the ground samples that were analyzed. The bark and wood samples used for nutrient analyses were obtained from the disk samples collected for use in determining moisture content and percent bark. The branch samples analyzed included both wood and bark and consisted of a representative composite sample of small, medium and large branches. All values obtained were recorded as percent dry weight.

RESULTS

The results obtained have been expressed in terms of: (1) the regression equations obtained for predicting the weights of biomass components of individual trees, (2) the levels of essential plant nutrients in the leaves, wood, bark and branches of young aspen, (3) biomass production of young aspen stands growing on upland sandy soils, and (4) the nutrient drain associated with harvesting stands of differing ages and at varying intensities of utilization.

REGRESSION EQUATIONS FOR PREDICTING THE BIOMASS COMPONENTS

Three types of regression equations were investigated in developing satisfactory regression equations for predicting the several biomass components. Without exception the equation using D^2H as the independent variable ($\underline{X}$) and employing the form

$$\mathrm{Ln}\hat{\underline{Y}} = \underline{b}_0 + \underline{b}_1 \mathrm{Ln}\underline{X}$$

did the best job of predicting each of the biomass components, based upon $\underline{r}^2$ values and the random nature of the residuals from regression. Ln is Log to the base "e" and the diameters at breast height (D) are in inches, the heights (H) used are in feet and the predicted dry weight ($\hat{\underline{Y}}$) is in grams. Table I summarizes the regression equation constants, the standard deviation from regression ($\underline{s}_{\underline{y} \cdot \underline{x}}$) and the square of the correlation coefficient ($\underline{r}^2$). The standard deviation from regression values are Log $\underline{e}$ and should only be used to calculate

$\underline{sy}^2$ and used with the equation

$$\mathrm{Ln}\hat{\underline{Y}} = \underline{b}_0 + \underline{b}_1 \, \mathrm{Ln}\underline{X} \pm s\hat{y}$$

to determine the standard error of estimate. To give the reader a feel for the accuracy of the prediction equations, $\hat{\underline{Y}}$, $\hat{\underline{Y}} + \underline{s}_{\hat{Y}}$, and $\hat{\underline{Y}} - \underline{s}_{\hat{Y}}$ were calculated in terms of real numbers (not Log e values) for the average-sized trees used in calculating the regression equations. To provide an additional insight into the relative accuracy of prediction, the average error of estimate (AEE) was calculated using the equation

$$\mathrm{AEE}\ \% = \frac{(\hat{\underline{Y}} + \underline{s}\hat{\underline{y}}) - (\hat{\underline{Y}} - \underline{s}\hat{\underline{y}})}{2\,\hat{\underline{Y}}} \cdot 100$$

Table I summarizes the results of the above calculations. The prediction equations for branches and for leaves had the greatest AEE and this is due primarily to the inclusion of intermediate crown class trees in the calculations. Intermediate trees had fewer branches and fewer leaves than dominant or codominant trees of the same size because of greater natural pruning.

BIOMASS COMPONENTS OF ASPEN STANDS

The relationship between tree size and weight of leaves, bark, wood, etc., for individual trees is of interest primarily because this allows field measurements of tree size and number of trees per acre to be converted into amounts of leaves, wood, bark, etc., that have been or can be produced per acre by aspen stands of various ages.

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[2] $\underline{s}_{\hat{Y}} + \underline{s}_{\hat{Y}\cdot\underline{x}} \sqrt{1 + 1/\underline{N} + \frac{\underline{x}^2}{\Sigma\underline{x}^2}}$

To establish the relationships between stand age and the biomass components on lower-quality aspen sites[3], a total of 26 field plots representing nine age classes were sampled. Temporary circular plots were established that varied in size from 1/10 to 1/100 (4/100 to 4/1000 ha) and included measurements in stands of ages 5, 6, 7, 8, 10, 13, 14, 18 and 22. Height, diameter and the number of stems per acre were measured. A computer program, using the previously described regression equations, was employed to convert the "tree size and tree numbers information" to dry weight per acre of wood, bark, leaves, branches, etc., for stands of ages 5 to 22 years.

The information obtained from the fully stocked aspen stands described in the previous paragraph was then used to calculate regression equations that established the changes that occur in the weight of leaves, wood, bark and branches (aerial portions only) as stand age increases. The calculation procedures described previously were used to develop equations relating biomass weight to stand age. Regression equations of the form: (1) $\hat{\underline{Y}} = \underline{b}_0 + \underline{b}_1\underline{X}_1 + \underline{b}_2\underline{X}_1^2$ and (2) $Ln\hat{\underline{Y}} = \underline{b}_0 + \underline{b}_1 Ln\underline{X}_1$ gave very similar $\underline{r}^2$ values but the log form of equation quite consistently gave the best random pattern of residuals from regression. "X" in the equations is stand age in years.

Table II summarizes the regressions obtained that relate stand age to biomass per acre. As mentioned in a previous paragraph, the information is for sandy upland sites with a site

[3]Site index, base age 30, of 48 to 52.

index of about 50, relatively low for good aspen growth. The average error of estimate (AEE, %) was calculated to give the reader a feel for the accuracy of the predictions being made for stands that are near the average age (12-16 years) of the stands used in establishing the regression equations.

Table III and Fig. 1 provide insight into the relationship between stand age and biomass. As might be expected, the curves for leaves and branches have the lowest slope, apparently reflecting natural pruning from below and the tendency for a stand to develop a fairly constant depth of live crown by the time they reach an age of 25-30 years. The shapes of all the curves are quite similar, differing primarily in slope. The $\underline{r}^2$ values and the average error of estimate were about what one would expect. Variation in site quality and level of stocking (deviation from fully stocked stands) appear to be the two principal reasons for not having $\underline{r}^2$ values greater than 0.90 and AEE values of less than 15%.

BIOMASS NUTRIENT LEVELS

Leaf, wood, bark and branch samples were collected from individual trees that varied in age from 5-20 years. Leaf samples were taken from 34 trees and 14 trees were employed in determining the nutrient levels for branches, bole bark, and bolewood. The sample trees were located on or near the areas where the previously described field plots were measured for the biomass/age relationships.

Table IV summarizes the levels of N, P, K, Ca and Mg obtained and are the levels used in subsequent calculations aimed at determining the nutrient accumulations in young aspen stands. There was no evidence of nutrient level differences due to age of the trees sampled when the sampling was confined to trees from ages 10 to 20 years. Unpublished data (1973) suggested that samples of bolewood, bole bark and branches from three-year-old suckers have higher nutrient levels than indicated in Table IV. Leaf analyses from three-year-old trees did not differ significantly from samples from older trees. The nutrient levels in the branch samples were the most variable of the types of tissue analyzed, reflecting the difficulty in coming up with comparable samples from trees that vary in size and age. The bark and wood of the branch samples were not separated for analyses and some of the variability apparently is due to differing levels of bark in the processed samples. Leaf analyses were made upon samples that included both the petiole and the blade. Samples using leaf blade tissue only have similar levels of P and Mg and higher levels of N, K and Ca. The values reported in Table IV are in close agreement with levels reported by Johnston and Bartos (1977) for quaking aspen in Utah and Wyoming.

NUTRIENT ACCUMULATION IN YOUNG STANDS

The accumulation of nutrients (and subsequent removal via harvesting) in young aspen stands is of particular interest when one considers the use of such sucker stands in short-rotation, intensive-management systems. Nutrient level accumulations in the aerial portion of the stand were estimated by combining the biomass weight information, calculated earlier, with the nutrient level information given in Table IV.

Table V provides in some detail a summary of how the per acre nutrient levels in leaves, bark, wood and branches change with stand age. Nitrogen and potassium offer interesting comparisons. The leaves in young stands contain 65 to 75% of the total accumulated nitrogen. At age 15 about 50% of the nitrogen is located in the leaves and the other 50% is distributed about equally in the wood, bark and branches. By age 23, nitrogen in the leaves represents 42% of the total accumulated nitrogen. Potassium, in contrast, has about 44% of the potassium located in leaves at age 5 and by age 23, the leaves contain only 18% of the total accumulated potassium. Changes in calcium levels are also interesting because of the very large amounts of calcium located in the bark. The bark contains 39% at age 5 and 51% of the calcium taken up by the stand at age 23.

Figure 3 illustrates the change in total N, P, K, Ca and Mg that occurs in young aspen stands as they increase in age, i.e., a leveling off of the total N, P, and K curves due to the decreasing contribution to the total biomass by the leaves and branches as the stand age increases. The data illustrate the importance of leaving the leaves on the site when harvesting stands less than 15 years old. The lower overall contribution of the leaves in the older-age stands (19-23 years) makes this approach of less importance for older-aged stands.

IMPACT OF WHOLE-TREE HARVESTING

Whole-tree and/or full tree harvesting usually implies chipping the entire aerial portion of the trees in a stand. Young aspen stands can quite easily be harvested either with or without removing the leaves from the site. Harvesting and removal of the entire aerial biomass implies removal of the levels of nutrients given in Table V and Fig. 3. Rotations from 10-20 years appear feasible under intensive management of aspen. As an illustration of the usefulness of the nutrient accumulation data generated in this study, the soil of one of the aspen sites[4] used in the study was evaluated for levels of total nitrogen and exchangeable levels of P, K, Ca, and Mg. Table VI illustrates the results of this comparison and includes an estimate of the amount of nutrients that have accumulated in the aerial portion of a 15-year-old aspen stand on that site. The soil data includes the amount of nutrients in the duff and litter and the top 24 inches of soil.

Table VII carries the illustration still further by comparing the nutrients removed by whole-tree harvesting (leaves not removed) with the estimated soil reserves and the estimated amount of nutrients added annually by precipitation. This comparison provides an insight on the impact of harvesting methods and rotation age on the long-term fertility of the site. Removal of the indicated amount of nutrients, although sizable, suggests that, when one considers the levels of available nutrients in the

[4]Upland loamy sand soil having 85% sand in the surface soil.

soils, amounts added by precipitation and the small amount of P, K, Ca and Mg slowly released by weathering, harvesting on a 15-year rotation will not seriously deteriorate the long-term fertility of the site. Important to maintaining adequate soil nutrient levels is the amount added by precipitation. Boyle and Ek (1972) values appear to have been confirmed by other workers. Stark (1973), working with pine in Montana, estimated similar amounts of nitrogen were being added to the soils in that area and data by Comerford and White (1977) suggest about one-third the amount of nitrogen and similar levels of P, K, Ca and Mg are being added to the soil in Minnesota by precipitation during the growing season.

Potassium is the single element where the reserves *vs.* removal ratio is low. However, when one considers the amount expected to be added through precipitation, there appears to be little reason for concern regarding soil depletion due to short-rotation forestry. These comments should not be construed to mean that growth of aspen could not be increased by fertilization of such sites. Fertilization of nearby native sucker stands (Einspahr and Wyckoff, 1978) indicates use of nitrogen and potassium can be expected to increase growth by 30 to 35%.

SUMMARY OF RESULTS

Based upon a study that involved field measurements taken in young quaking aspen stands in north central Wisconsin, regression equations were established that allow the prediction of the dry weight of leaves, bolewood, bole bark, branches, and total aerial biomass of individual trees. The regression equations obtained were of the form $Ln\hat{\underline{Y}} = \underline{b}_0 + \underline{b}_1 Ln\underline{X}_1$, where $\underline{X}$ is the diameter^2 x total height. Estimates of biomass production on upland sandy soils (site index 48-52) were obtained for stands that varied in age from 5 to 22 years. Regression equations were calculated that established the relationship between stand age and per acre production of leaves, wood, bark and branches. Levels of N, P, K, Ca and Mg were determined for leaves, wood, bark and branches. By combining nutrient level data with biomass production, nutrient drain information was developed that could be interpreted in terms of several alternative methods of harvesting and at rotation ages from 5 to 22 years.

Soils and site index information obtained for the study areas made it clear that the sites involved must be considered to be relatively low in terms of growth potential for quaking aspen. The nutrient drain associated with whole-tree harvesting on a 15-year rotation was examined. The results indicate that, if the leaves are left on the site, even low-quality, sandy soils are not expected to deteriorate seriously when cropped every 15 years for prolonged periods of time. Removal of the leaves greatly increases the drain and, for rotation ages less than 10 years, would mean periodic fertilization would be required to maintain adequate nutrient levels.

The information generated is based upon measurements made in aspen growing on upland sandy sites in north central Wisconsin. The regression equations that make it possible to predict such biomass components as bark, wood, leaves, etc., have a fairly wide application and can be appropriately used throughout the Lake States and Northeast to convert tree size information into dry weight of wood, bark, branches and leaves. Use of the biomass production and nutrient drain estimates should be restricted to use with stands growing on similar sites in the Lake States and Northeast. To obtain area biomass production and nutrient drain data for better quality sites will require additional sampling (biomass nutrient levels and tree growth) in quaking aspen stands growing on better soils.

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Table 1. Tree size *vs.* biomass weight

Regression equation constants, standard deviation from regression, r^2 and average error of estimate

Biomass component	No. trees	Regression equation constants b_0[a]	b_1[a]	$s_{y \cdot x}$[a]	r^2	AEE[b], %
Leaves	88	3.191	0.520	0.341	0.89	35
Bolewood	208	3.651	0.943	0.168	0.99	17
Bole bark	208	2.595	0.846	0.231	0.98	23
Total branches	122	2.683	0.776	0.395	0.93	41
Total biomass	122	4.339	0.880	0.160	0.99	16

[a] Regression equation constants and $s_{y \cdot x}$ given as Log *e* (Ln) values.

[b] Average error of estimate, % — for mean tree size used in calculating the regression equations.

Table 2. Stand age *vs.* biomass per acre

Regression equation constants, standard deviation from regression and r^2 values

Biomass component	No. age class	b_0[a]	b_1[a]	$s_{y \cdot x}$[a]	r^2	AEE[b], %
Leaves	9	5.275	0.462	0.134	0.70	14
Bolewood	9	4.888	1.497	0.286	0.84	30
Bole bark	9	4.018	1.258	0.237	0.85	24
Branches	9	4.242	1.087	0.204	0.85	21
Total biomass	9	5.696	1.342	0.254	0.85	26

[a]Regression equation constants and $s_{y \cdot x}$ given as Log *e* (Ln) values.

[b]Average error of estimate, % — for the mean stand age used in calculating the regression equations.

Table 3. The influence of stand age on biomass accumulation

Stand age	Weight in pounds/acre[a]				
	Leaves	Bolewood	Bole bark	Branches	Total biomass
5	906	3,255	928	882	5,691
7	1,058	5,387	1,418	1,272	8,939
9	1,188	7,848	1,945	1,671	12,524
11	1,305	10,597	2,503	2,077	16,394
13	1,409	13,609	3,089	2,492	20,515
15	1,506	16,859	3,698	2,911	24,857
17	1,594	20,335	4,328	3,336	29,404
19	1,680	24,017	4,979	3,764	34,138
21	1,760	27,900	5,647	4,196	39,046
23	1,835	31,970	6,331	4,633	44,115

[a]Values computed from regression equations of the form $Ln\hat{\underline{Y}} = \underline{b}_0 + \underline{b}_1 Ln\underline{X}_1$, to convert to kilograms/hectare multiply values given by 1.1206.

Table 4. Weighted average levels of nutrients

Type material	No. trees	Age trees, yr	% o.d. wt. N	P	K	Ca	Mg
Leaves	34	5-20	2.48	0.20	0.82	1.32	0.25
Branches	14	10-20	0.37	0.07	0.27	0.62	0.07
Bole bark	14	10-20	0.37	0.08	0.43	1.41	0.14
Bole wood	14	10-20	0.07	0.01	0.09	0.10	0.02

Table 5. Levels of nutrients accumulated in young aspen stands as a function of stand age

Stand age	Component	Weight in lb/acre				
		N	P	K	Ca	Mg
5	Leaves	22.47	1.81	7.43	11.97	2.27
	Bolewood	2.27	0.33	2.93	3.26	0.66
	Bole bark	3.44	0.75	3.99	13.10	1.30
	Branches	3.26	0.62	2.38	5.47	0.62
7	Leaves	26.24	2.12	8.69	13.98	2.65
	Bolewood	3.77	0.53	4.85	5.38	1.08
	Bole bark	5.25	1.12	6.09	20.00	1.98
	Branches	4.70	0.88	3.44	7.89	0.88
9	Leaves	29.48	2.38	9.75	15.68	2.98
	Bolewood	5.49	0.79	7.06	7.85	1.57
	Bole bark	7.19	1.57	8.36	27.43	2.71
	Branches	6.17	1.17	4.52	10.36	1.17
11	Leaves	32.37	2.60	10.69	17.22	3.26
	Bolewood	7.41	1.06	9.55	10.61	2.12
	Bole bark	9.26	2.01	10.76	35.28	3.51
	Branches	7.70	1.46	5.60	12.88	1.46
13	Leaves	34.95	2.82	11.55	18.59	3.53
	Bolewood	9.53	1.37	12.24	13.60	2.71
	Bole bark	11.42	2.47	13.27	43.55	4.32
	Branches	9.22	1.74	6.73	15.46	1.74
15	Leaves	37.35	3.02	12.35	19.89	3.77
	Bolewood	11.80	1.68	15.17	16.87	3.37
	Bole bark	13.67	2.95	15.90	52.15	5.18
	Branches	10.76	2.03	7.85	18.04	2.03
17	Leaves	39.54	3.20	13.08	21.04	3.99
	Bolewood	14.24	2.03	18.30	20.33	4.06
	Bole bark	16.01	3.46	18.61	61.03	6.06
	Branches	12.35	2.34	9.02	20.68	2.34
19	Leaves	41.67	3.35	13.78	22.18	4.21
	Bolewood	16.80	2.40	21.61	24.01	4.81
	Bole bark	18.41	3.99	21.41	70.21	6.97
	Branches	13.94	2.62	10.16	23.33	2.62
21	Leaves	43.64	3.53	14.42	23.22	4.41
	Bolewood	19.54	2.80	25.11	27.89	5.58
	Bole bark	20.90	4.52	24.28	79.62	7.92
	Branches	15.52	2.93	11.33	26.02	2.93
23	Leaves	45.49	3.66	15.04	24.21	4.59
	Bolewood	22.38	3.20	28.78	31.97	6.39
	Bole bark	23.42	5.07	27.23	89.26	8.86
	Branches	17.13	3.24	12.50	28.73	3.24

Table 6. Composite soil and biomass data for 15-year-old sucker stand

Type of material	Ovendry wt./acre, lb	Total amount of nutrients, lb/acre				
		N	P	K	Ca	Mg
Soil 0-24 inches	--	4,000	570[a]	470[a]	3,080[a]	460[a]
Litter	20,080	353.4	64.2	52.2	528.0	66.2
Stem wood	16,860	11.8	1.7	15.2	16.9	3.4
Stem bark	3,700	13.6	3.0	15.9	52.1	5.2
Branches	2,910	10.8	2.0	7.8	18.0	2.0
Leaves	1,510	37.4	3.0	12.3	19.9	3.8

[a]Exchangeable levels in 0-24 inch layer of mineral soil.

Table 7. Levels of major nutrients removed *vs.* nutrient reserves 15-year-old aspen stand, lb/acre

Element	Removed by harvest	Available in soil[a]	Added annually via precipitation[b]	Ratio of available reserves *vs.* removal
N	36.2	2,150[c]	14.6	59
P	6.7	630	0.4	94
K	38.9	520	2.8	13
Ca	87.0	3,600	5.0	41
Mg	10.6	540	0.9	51

[a] Includes nutrients in litter as well as mineral soil.
[b] Value based upon average value estimates by Boyle and Ek (1972) for Wisconsin.
[c] Amount available estimated to be 1/2 of total nitrogen. Annual amount available has been estimated to be as low as 1% of total.

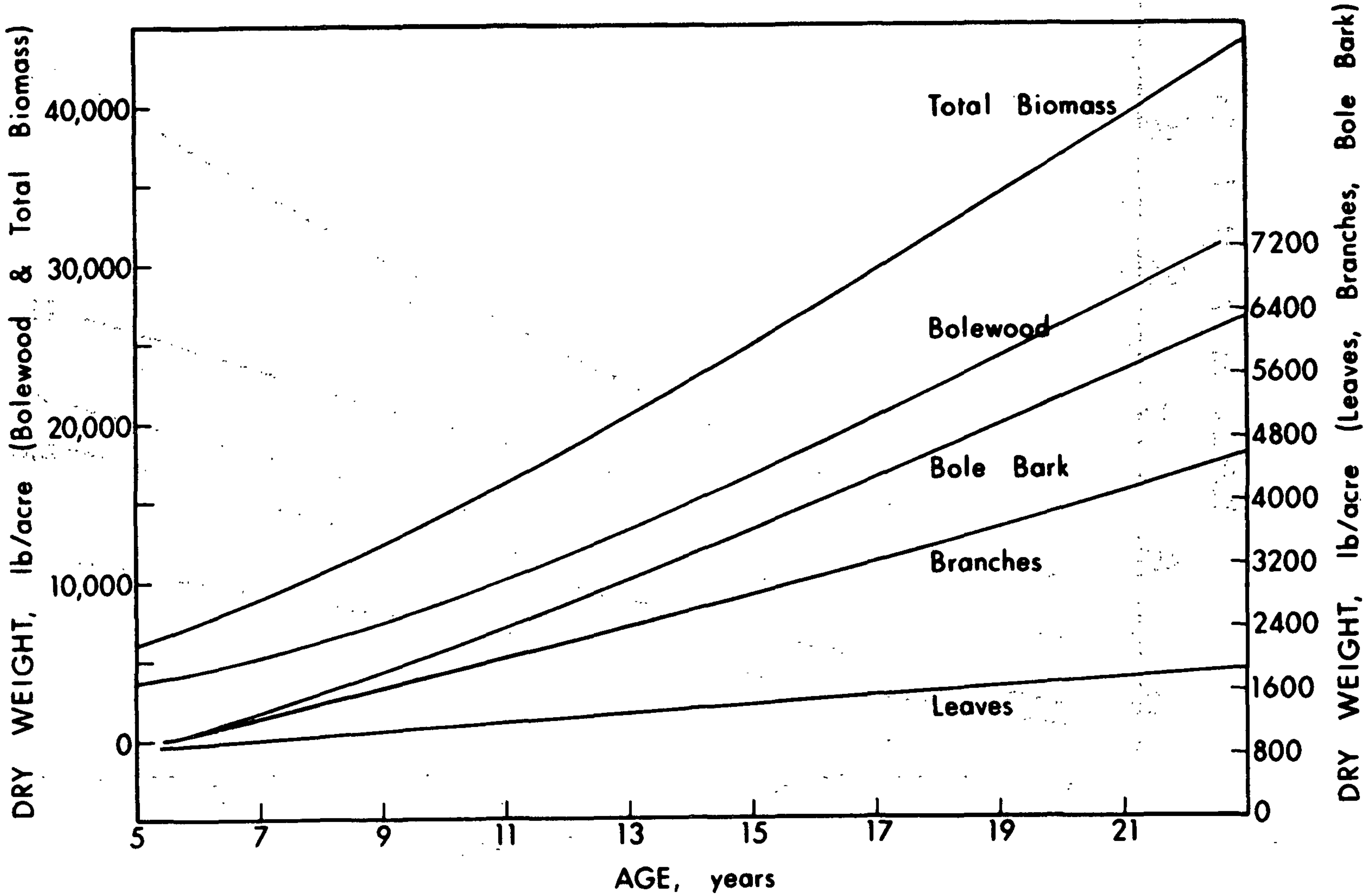

Figure 1. Biomass/Age Relationship in Quaking Aspen Stands

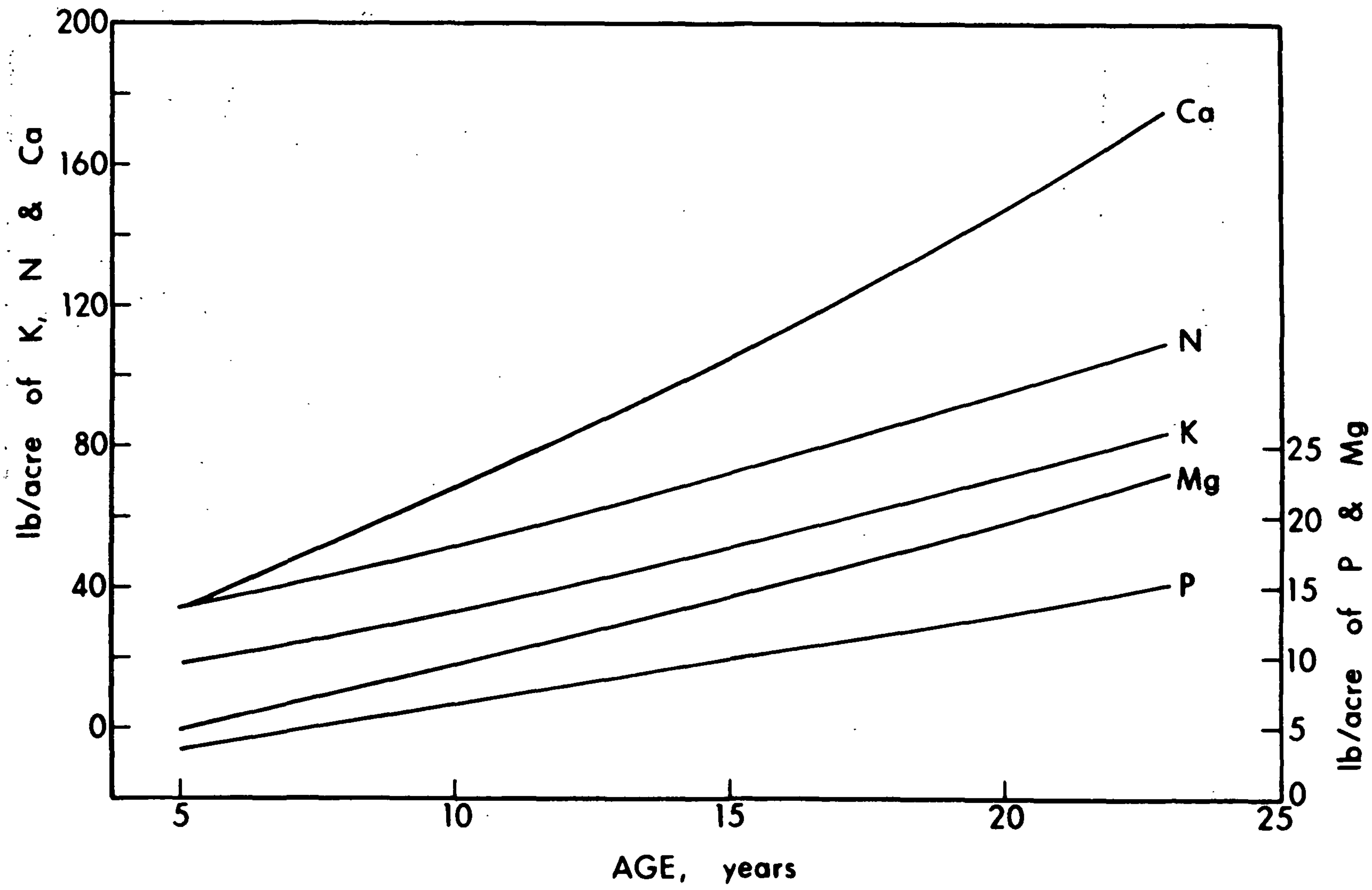

Figure 2. Total Nutrients Accumulated in the Aerial Biomass of Young Aspen Stands